Exclusive electromagnetic production of strangeness on the nucleon : review of recent data in a Regge approach.

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In view of the numerous experimental results recently released, we provide in this letter an update on the performance of our simple Regge model for strangeness electroproduction on the nucleon. Without refitting any parameters, a decent description of all measured observables and channels is achieved. We also give predictions for spin transfer observables, recently measured at Jefferson Lab which have high sensitivity to discriminate between different theoretical approaches.

Regge theory provides a simple and elegant framework to describe exclusive hadronic reactions above the resonance region [1–3]. We have presented in references [4–7]) a Regge model for meson photo- and electroproduction reactions which is based on the exchange of one or two meson Regge trajectories in the t-channel. The very few free parameters in this approach are the coupling constants of the first particle materialization of the Regge trajectory at the hadronic vertices along with the mass scales of monopole form factors at the electromagnetic vertices in the case of electroproduction. Basically, all available observables are decently and "economically" described by this approach for a plethora of elementary channels : photo- and electroproduction on the nucleon of $\pi^{0,\pm}$ and K^+ as well as $\rho^0, \omega, \phi, \gamma$ [8,9] and η, η' [10]. Surprisingly, in some cases, data down to W< 2 GeV center of mass energies, therefore supposedly in the resonance region, can be succesfully described : this could be interpreted as a manifestation of the reggeon-resonance duality hypothesis [11]. Why this duality seems to work for some channels and not for some others still remains an open question.

Recently, numerous experimental data have been released by the Jefferson Lab, ELSA, GRAAL and SPRING8 facilities in the kaon production sector. This motivates this study which compares the Regge model to these new observables and channels, without any change of the parameters. Our model is fully described in Refs. [4–7]. In those works, we found that, for strangeness electromagnetic production, it allows to describe the $\gamma^{(*)} + p \rightarrow K^+ + \Lambda$ and $\gamma^{(*)} + p \rightarrow K^+ + \Sigma$ reactions through the exchange of only two trajectories in the t-channel : K and K^*. The coupling constants at the $(K, (\Lambda, \Sigma), N)$ and $(K^*, (\Lambda, \Sigma), N)$ vertices were derived and fitted from the photoproduction study [4,5] where all existing high energy data could be satisfactorily described :

$$g_{K\Lambda N} = -11.54 \ , \ g_{K^*\Lambda N} = -23.0 \ , \ \kappa_{K^*\Lambda N} = 2.5,$$
$$g_{K\Sigma N} = 4.48 \quad , \ g_{K^*\Sigma N} = -25.0 \ , \ \kappa_{K^*\Sigma N} = -1.0 \qquad (1)$$

In the electroproduction case, the other parameters of the model are the two (squared) mass scales of the monopole form factors at the $\gamma, K, (K, K^*)$ vertices, which were taken both equal to 1.5 GeV^2 [7] in order to fit the high Q^2 behavior of the data.

Finally, let's recall that one essential feature of the model is the way gauge invariance is restored for the t-channel K exchange by proper "reggeization" of the s-channel nucleon pole contribution. As detailed further below, this is the key element to describe the slow decrease with Q^2 of the $R = \sigma_L/\sigma_T$ ratio for the $K^+\Lambda$ channel, a feature which was found to be difficult to accomodate in all other approaches.

These data, first published in [12], have actually been recently re-analysed [13] by the JLab collaboration E93018. We compare on Fig. 1 the Regge model predictions [7] with these new Q^2 dependence for the experimental transverse (σ_T) and longitudinal (σ_L) cross sections, along with their ratio (R), for both the Λ and Σ channels. The corrections due to the new analysis are non-negligible for the absolute values of the longitudinal and transverse cross sections and affect significantly the slopes of the Q^2 dependences. Our (unchanged) model gives now a much better description of σ_L but it significantly underestimates σ_T at large Q^2, for both channels. However, the ratio R is still very well reproduced and displays a slow decrease as Q^2 increases.

The curves of the lower panels of Fig. 1 illustrate that the origin of the decrease with Q^2 of the ratio R is actually not so much the result of the Regge treatment of the K and K^* t-channel propagators but, rather, as mentionned before, of the particular way gauge invariance is restored (i.e. by reggeizing the nucleon s-channel and kaon t-channel diagrams and assigning to them the *same* electromagnetic form factor). The reggeization is nevertheless necessary to ensure a correct normalization of (σ_T) and (σ_L) as standard Feynman propagators would produce cross sections higher by factors of 2 to 5 at these energies.

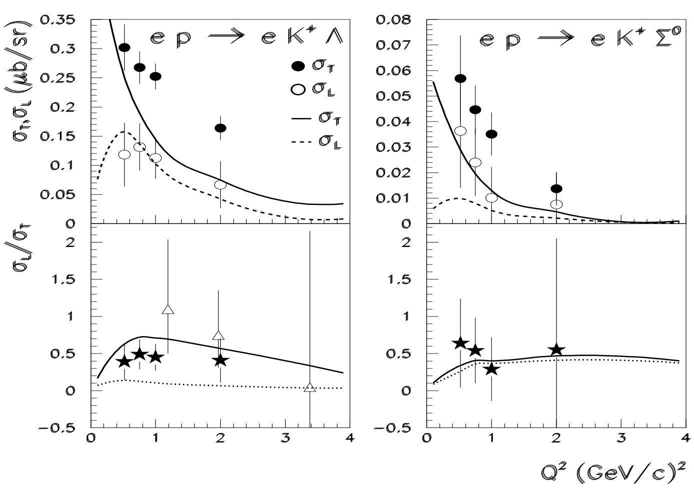

FIG. 1. Q^2 dependence of σ_T and σ_L (upper panels) and of their ratio $R = \sigma_L/\sigma_T$ (lower panels) for the $\gamma^* + p \rightarrow K^+ + \Lambda$ reaction (left panels) and $\gamma^* + p \rightarrow K^+ + \Sigma$ reaction (right panels), at W = 1.84 GeV. Experimental data points are from : ($\bullet$, $\circ$, $\bigstar$) : Ref. [13] and ($\triangle$) : Ref. [14]. For the lower panels, the full curve is the model with reggeized K and K^* t-channel exchanges whereas the dotted curve has standard Feynman poles for the K and K^* propagators.

A better agreement with these new data could certainly be achieved by changing the values of the K and

K^* form factor mass scales but this would destroy the nice agreement with the other kaon electroproduction data [14–20], for which $W > 2.1$ GeV and which were presented in Ref. [7]. We prefer to interpret this discrepancy as room for potential additionnal processes at these lower energies (W=1.84 GeV), such as s-channel resonances. It has indeed already been observed that the well known nucleon resonances have larger transverse photocouplings than longitudinal ones [21,22].

Fig. 2 shows the Q^2 dependence of the $\frac{\Sigma}{\Lambda}$ ratio for both transverse and longitudinal cross sections. Again, a good agreement with the data is found without any additional refitting of the parameters of the model. In our t-channel approach, only the kaon exchange contributes to σ_L (like for the pion form factor in pion electroproduction, the best way to access the kaon form factor at intermediate and large Q^2 is to isolate σ_L, as it is mostly insensitive to K^* exchange). This is why the $\frac{\Sigma}{\Lambda}$ ratio for σ_L is basically constant in our model. However, for the transverse part of the cross section, the K and K^* contribute with different weights for the Λ and Σ^0 channels and therefore, the $\frac{\Sigma}{\Lambda}$ ratio is no longer constant for σ_T.

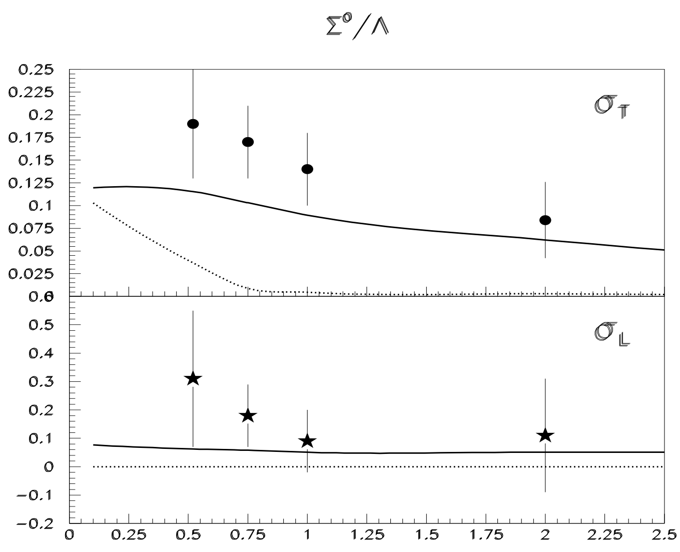

FIG. 2. Q^2 dependence of the ratio of the $\gamma^*+p \to K^+ + \Sigma$ to the $\gamma^*+p \to K^+ + \Lambda$ forward (θ_K^{cm}=0) differential cross sections at W = 1.84 GeV. Upper panel: transverse cross section; lower panel: longitudinal cross section. Full curve : K+K^* exchanges; dotted curve : only K^* exchange. Experimental data points are from Ref. [13].

Fig. 3 displays the photoproduction data with, in particular, the latest results from the JLab/CLAS collaboration [23] which are about 20-25% above the previous Bonn/Saphir data [24]. For the Λ channel, there are structures in the experimental data ("bumps" around W≈ 1.75 GeV and 1.95 GeV) which hint to s-channel resonances excitations and which our model can obviously not reproduce as it is purely a t-channel model ; however, the JLab experimental data (for the forward angles) lies now, in average, very close to the Regge model, unchanged from Ref. [4,5]. This supports, at the 10-15% level and for this channel, the concept of a global duality between the sum of all t-channel exchanges and all s-channels excitations.

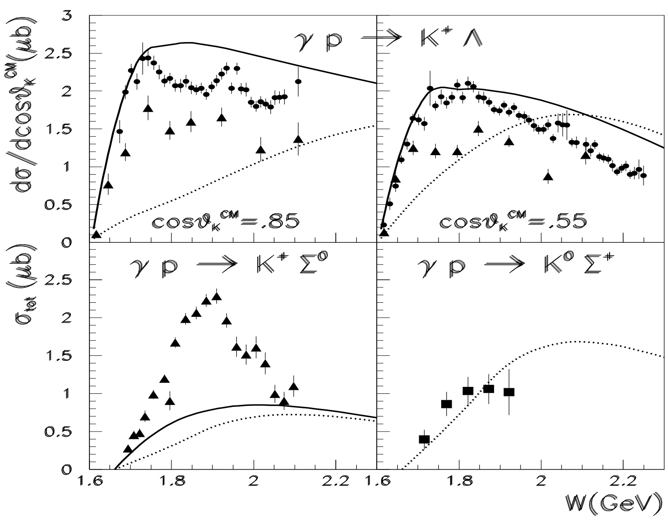

FIG. 3. W dependence of the $\gamma + p \to K^+ + \Lambda$ *differential* cross section at $\cos(\theta_K^{CM}) \approx 0.85$ and $\cos(\theta_K^{CM}) \approx 0.55$ (left and right upper panels respectively) and of the $\gamma+p \to K^+ + \Sigma$ and $\gamma + p \to K^0 + \Sigma^+$ *total* cross sections (left and right lower panels respectively). Full curve : K+K^* exchanges; dotted curve : only K^* exchange. Experimental data points are from Refs. [23] (circles), [24] (triangles) and [25] (squares).

As to the Σ^0 channel, the Bonn/Saphir data [24] largely exceeds the calculation of our model. The data point to a prominent s-channel resonance structure around W ≈ 1.9 GeV. It would be interesting to explore the kinematical region $W > 2.1$ GeV to see if our model overestimates the experimental data which would therefore make up for the underestimation of our model in the $W < 2.1$ GeV and which would restore, in average, the duality idea. This high energy domain can be explored by the JLab CLAS collaboration up to $E_\gamma \approx 6$ GeV (W≈ 3.5 GeV).

The $K^0\Sigma^+$ channel can be calculated in a straightforward way, without any additional parameter by taking into account only the K^{0*} t-channel exchange (as a real photon cannot elastically couple to the neutral spinless K^0) and using $g^2_{\gamma K^0 K^{*0}} =$

$g^2_{\gamma K^+ K^{*+}} \Gamma_{K^{*0}\to\gamma K^0}/\Gamma_{K^{*+}\to\gamma K^+} \approx 2.3\ g^2_{\gamma K^+ K^{*+}}$ with the radiative widths taken from Ref. [21]. Figure 3 shows a very nice agreement between our calculation and the Bonn/Saphir data of Ref. [25] which can be interpreted as an absence of s-channel excitation in this channel (which brings constraint on the isospin of the hinted resonance around W≈1.9 GeV decaying into the Σ^0 channel). If the Σ^+ channel is indeed produced by pure t-channel exchange, these data provide us with a strong constraint (and in our case, a nice confirmation) of the strength of the K^* exchange, which is the only allowed leading Regge trajectory and whose coupling constants have been derived independently [5].

well at forward angles the magnitude and the sign of the Λ and Σ recoil polarizations [7].

An electroproduction experiment at JLab [27] has measured for the first time, the transfered polarisation from a longitudinally polarized beam to the Λ recoil hyperon in the exclusive reaction $e + p \to e' + K^+ + \Lambda$. We show on Fig. 5 the only two transferred polarization components $P'_{x'}$ and $P'_{z'}$[1] which are non-zero when integrated over Φ, the azimuthal angle between the leptonic and the hadronic planes. The longitudinal spin transfer component ($P'_{z'}$) is well reproduced at the very forward angles. The sideways component spin transfer component ($P'_{x'}$) is well reproduced over the full angular range.

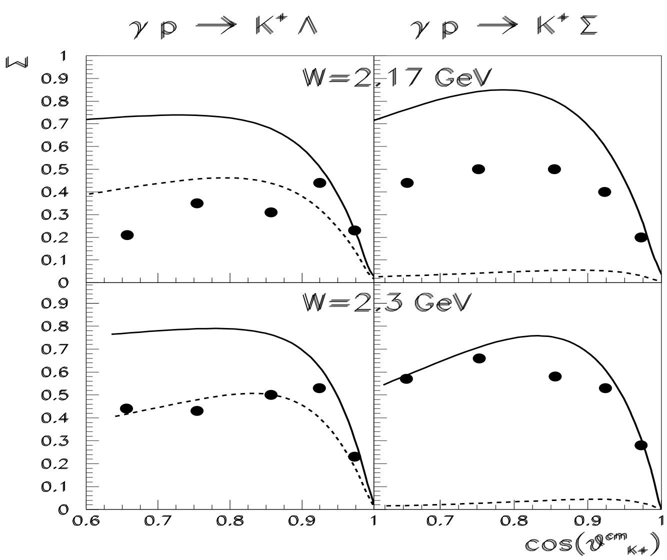

FIG. 4. $\cos(\theta^{cm}_{K^+})$ dependence of the photon asymmetry for the $\gamma + p \to K^+ + \Lambda$ (left) and $\gamma^* + p \to K^+ + \Sigma$ (right) processes at W = 2.17 GeV (or E_γ=2.05 GeV) and W = 2.3 GeV (or E_γ=2.35 GeV). Experimental data points are from Ref. [26]. Full curve : K+K^* exchanges, dashed curve : K exchange.

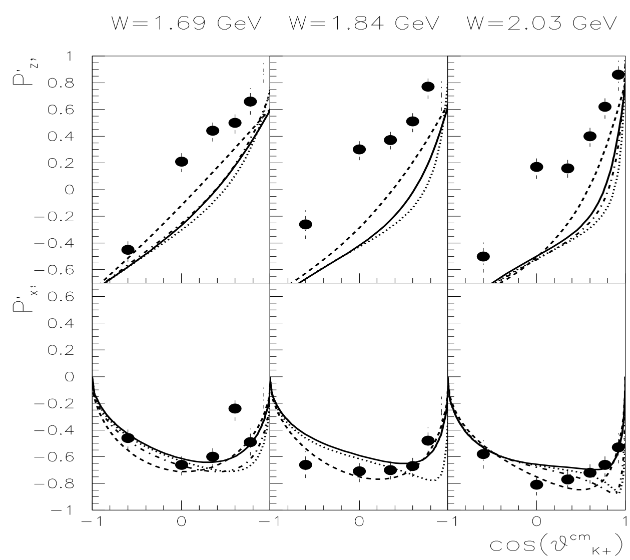

FIG. 5. $\cos\theta^{cm}_{K^+}$ dependence of the transfered Λ polarization in $e + p \to e' + K^+ + \Lambda$ (left) for $E_e = 2.5$ GeV and $< Q^2 >= 0.8$ GeV^2. Full curve : K+K^* reggeized exchange. Dashed curve : K reggeized exchange. Dotted curve : K^* reggeized exchange. Dash-dotted curve : K+K^* standard Feynman pole exchange. Experimental data points are from Ref. [27].

Turning now to polarization observables, Fig. 4 shows the photon asymmetry recently measured by the Spring-8 collaboration at the LEPS facility [26] in photoproduction for both the Λ and Σ channels. The general trend of the data is reproduced by the model, in particular the sharp rise of the beam asymmetry at very forward angles (indication of the dominance of the natural parity K* exchange). At smaller center of mass energies and larger angles, the discrepancies between theory and data become more pronounced. This should not come as a surprise as Regge theory is essentially valid at high energies and forward angles. It is nevertheless certainly of great interest to probe the limits of this model through such data. Let's also remind that the Regge model describes

We have plotted, along with the standard K+K^* reggeized exchanges which constitutes our full model, the individual contributions of the reggeized K and K^* exchanges. We also show the calculation carried out with standard Feynman propagators of the type $1/(t - m^2_{(K,K^*)})$, instead of Regge propagators of the type $s^{\alpha_{(K,K^*)}(t)}$. It can be seen that these observables

[1]where x' and y' refer to the cartesian coordinates in the $\gamma^* - p$ center of mass frame with the z-axis along the direction of the produced kaon

are actually barely sensitive to these variations and that basically any model based on K and/or K^* t-channel exchange, whatever is the chosen prescription (Feynman or Regge type pole), gives a decent description of the data. However, it should be noted that, when introducing s-channel resonances processes (see, for instance the isobaric models cited in Ref. [27]), such double polarization observables are very sensitive to resonance properties and allow to discriminate rather precisely between various sets of nucleon resonances participating in the reaction.

In summary, the latest experimental results released in the domain of open strangeness electromagnetic production on the nucleon confirm that our "simple" Regge model surprisingly reproduces the gross features of the data, even for $W < 2$ GeV. It thus provides an economical description and a simple explanation of the data, hinting that a sort of reggeon-resonance duality is at work here. Where it fails, it gives a useful hint that other mechanisms than simple t-channel mechanisms are necessary. In the difficult task of putting into evidence new nucleon resonances in the strangeness channel which are overlapping or hidden into large backgrounds, this sort of clue, i.e. the contribution of non-resonant t-channel and Born mechanisms, is certainly much needed.

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